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THE TOHOKU TSUNAMI OF 11 MARCH 2011 AS RECORDED ON THE RUSSIAN FAR EAST

G. V. Shevchenko

Institute of Marine Geology and Geophysics FEB RAS, Yuzhno-Sakhalinsk, Russia

T. N. Ivelskaya

Sakhalin Tsunami Warning Center, Yuzhno-Sakhalinsk, Russia

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ABSTRACT

The source region of the catastrophic Tohoku tsunami of 11 March 2011 was near the Russian Far East, thus a warning was issued for threatened coasts of the Kuril Islands and Kamchatka. The tsunami was clearly recorded by a number of coastal tide gauges and by bottom pressure stations (including the Russian DART 21401). The recordings by these instruments were used to estimate the major characteristics of the tsunami waves, including arrival times, maximum heights, duration of signals and main wavelength periods. Further analysis indicated significant differences in the spectral characteristics of the waves propagating eastward toward North America from those directed in a northwest direction, towards the Russian Far East. The main peaks of the eastward propagating tsunami waves were of relatively high frequency, while those propagating in a northwest direction, were mainly of low frequency. At far-field stations, the resonant periods associated with local topographic effects were predominant in the spectra.

Keywords: *tsunami, open-ocean DART station, coastal station, arrival time, maximum height, spectra, wavelet analysis*

1. INTRODUCTION

The source of the catastrophic Tohoku tsunami of 11 March 2011 was close to the Russian Far East. The tsunami presented a serious threat for the Kuril Islands and Kamchatka so a warning was declared for these regions to evacuate people from low-lying areas and for ships to sail to the open ocean. The tsunami was clearly recorded by a number of coastal tide gauges and bottom pressure stations. A network of precise coastal telemetric gauges, deployed by Russia during the last two years, effectively measured the tsunami at 17 sites – specifically at the Kuril Islands (3), Kamchatka (2), Commander Islands (1), Sakhalin Island (7) and Primorie (4). The tsunami was also recorded by the Russian open-ocean DART station 21401, located east of the South Kuril Islands and by several temporary autonomous bottom pressure stations. The data from DART buoy 21418 located near Japan and buoy 21419 located near the Middle Kuril Islands was used for comparison. These instruments enabled us to estimate major characteristics of the observed tsunami waves, including arrival times, maximum wave heights, duration of the signals and main periods. FFT and wavelet analysis were used to describe the spectral content of the tsunami signals. The present study provides a comprehensive analysis of the middle-field (South Kuril Islands and adjacent northeastern part of Hokkaido Island) and far-field (Kamchatka, Bering and Sakhalin Islands, Primorie) tsunami characteristics on the Russian Far East. The latter area has not experienced a major Pacific tsunami in nearly 50 years. The main goal of the study was to examine the effects of local bottom topography and of coastline geomorphology on the spatial variability of tsunami heights in this particular region of the Russian Far East.

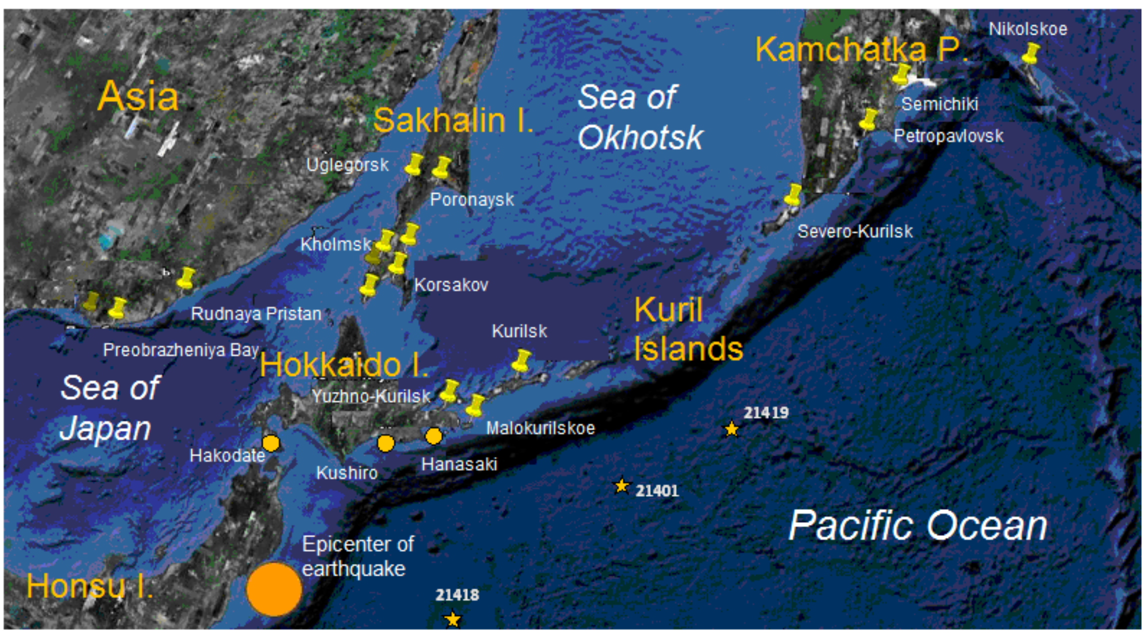

Fig. 1. Stations which recorded the Tohoku 11.03.2011 tsunami. DART stations marked by stars; coastal gauges of the Japanese Tsunami Warning Service marked by yellow circles and Russian TWS coastal telemetric gauges marked by yellow buttons. The earthquake epicenter of earthquake is marked by the orange circle.

2. THE TOHOKU EARTHQUAKE AND TSUNAMI

The great earthquake occurred on March 11, 2011 at 5:46:23 UTC. The US Geological Survey's National Earthquake Information Center (NEIC/USGS) estimate of moment magnitude was $M_W = 9.0$ with epicenter at 38.32° N, 142.37° E, about 129 km east of Sendai and a focal depth of about 24 km. Tsunami waves ranging up to 12-15 m (up to 30 m in some places) struck the northwest coast of Honshu Island, destroying numerous coastal towns and villages, killing about 20,000 people (precise number of deaths is not determined yet). All recording stations along the stricken area were destroyed and the tsunami wave heights were estimated by the extent of the flooding zone - thus representing approximate values, which may be revised by further surveys.

The most recent catastrophic tsunami in this area of Honshu had been generated by the great earthquake (M = 8.4) of March 3, 1933. That particular tsunami was responsible for about 3000 deaths, the destruction of about 6000 buildings and the sinking or destruction of about 12,000 boats (Soloviev and Go, 1974). Most damaged were coastal settlements in the Iwate Province, where tsunami heights averaged from 12~14 m with up to a 29 m maximum. The heights on the coast of Miyagi Prefecture were slightly lower and ranged from 8-12 m with a maximum height of 21 m. At some places of other prefectures, catastrophic tsunami wave were also observed, with heights reported at 19.5 m in Hirota, 26.7 m in Nezaki, etc.

The waves of approximately the same heights were observed on the northeastern coast of Honsu Island in 1611and 1898, as well. Although the region is densely populated, the high tsunami hazard was largely underestimated – thus the 2011 tsunami caused unprecedented deaths and destructions, in spite of a perfectly functioning Japanese TWS and a good program of public preparedness.

3. TSUNAMI CHARACTERISTICS BASED ON THE DATA FROM THE DEEP-WATER DART STATIONS

In the late 1960s - early 1970s, the Institute of Marine Geology and Geophysics of the USSR's Academy of Sciences (present day IMGG) was the leading organization in the development of near-bottom, hydrostatic pressure recorders. Such recorders were intended for measurements of sea level oscillations on the shelf and in the open sea. The principal aim of experiments in the South Kurils was to determine the characteristics of tsunami waves at different distances away from the shore. Changes recorded in the open sea, where refraction, scattering and other local coastal effects are less intensive, are important in identifying wave field formation peculiarities, caused by processes in the source region of an underwater earthquake. Such measurements help assess tsunami wave enhancement as it approaches the shore and in solving other important problems.

The main initiator of such studies was Academician Sergey Soloviev and the first measuring instruments and experimental applications were made by Victor Zhak (Zhak and Soloviev, 1971). The sea level gauges were deployed in the open ocean and connected by cable with the land-based recorder. Later, autonomous instruments with magnetic storing capability were constructed and similarly deployed. These efforts were implemented in 1980 on the shelf of Shikotan Island and led to the first successful recording of a tsunami in the open ocean (Dykhan et al., 1981). Based on such precise instrumental data, differences between the real tsunami characteristics in coastal and deep-water environments were identified for the first time. These results - based on deep-water measurements - became the fundamental concept on which the early tsunami warning system functioned. The same operational concept was actively developed and adopted by the Pacific Tsunami Warning Center, headquartered in Honolulu, Hawaii. Presently, the information about deep ocean level oscillations is communicated from the DART stations network, which now covers nearly the entire Pacific Basin and is connected with the national Tsunami Warning Systems using satellite telemetry.

Let us consider the 2011 Tohoku tsunami records from the deep-water stations located in the northwest Pacific, near Honshu and Kuril islands (Fig. 1). DART stations 21401 and 21419 provided quality data. DART station 21418 operated with several singular failures that were corrected in the manual mode. Data provided by DART station 21416 were of low quality and therefore were not used in the present study. The 20-h long (from 4:00 to 24:00) segments were considered and the preliminary calculated tide level was subtracted from the measured values. A similar oscillation pattern was recorded at all stations. First, there was a strong singular wave, and then it was followed by a long sea level oscillation of significantly lower intensity, which was no more than 10 cm in amplitude (Fig. 2).

In all cases, high-frequency oscillations were recorded prior to the main wave arrival (this is typical for recorders of near-bottom hydrostatic pressure, which is changed by seafloor vibrations caused by the seismic Rayleigh wave. DART station 21418 which was the closest to the earthquake epicenter recorded the tsunami arrival at 6:11 UTC, with the main peak at 6:19 (the positive deviation from null average level was 187 cm). In contrast to wind wave theory - which considers the length between trough and crest of a wave - the tsunami study implies that the more important parameter to be estimated is the positive deviation value of the sea level oscillation, which determines the character of tsunami impact on shores and coastal localities as well as the extent of subsequent inland inundation. The negative phase is also important (maximal one was 94 cm at 6:26), since it is related to dynamic loads when the wave backwashes - but this parameter is usually considered separately.

At DART station 21401, which is located beyond the deep-water trench in the area of Iturup Island, the first tsunami arrival was significantly later, at 6:43. The recorded peak wave height here (+67 cm) was recorded at 6:53 and the highest negative deviation (-26 cm) at 7:04. The latest time was when the wave reached the most distant DART station 21419, which is located in the area of Middle Kuril Islands. The peak deviation at this station was +54 cm. at 7:16 and the negative one was -26 cm. at 7:26. This indicates a gentle decrease in wave amplitude as coming from the source – which is usually related to wave front dispersion and attenuation with distance.

To investigate the main periods of tsunami-induced oscillations, the method of spectral-time analysis was used by the present study - a kind of the wavelet analysis STA (Dzienovski et al., 1969), implied for study of changes in spectral amplitudes in time. The calculation was performed for periods from 2 to 100 minutes (frequencies from 0.5 to 0.01 cycles per minute). The matrix of spectral amplitudes was normalized to 30 cm for DART station 21418 and to 10 cm for the two others. The calculation results are illustrated in Fig. 3.

A certain difference in spectral characteristics was derived for different stations which needs to be emphasized. For example at DART station 21418, the signal was generally of high frequency, where the main peak had periods of 6~8 min and the subsequent one had periods of 15~20 min.

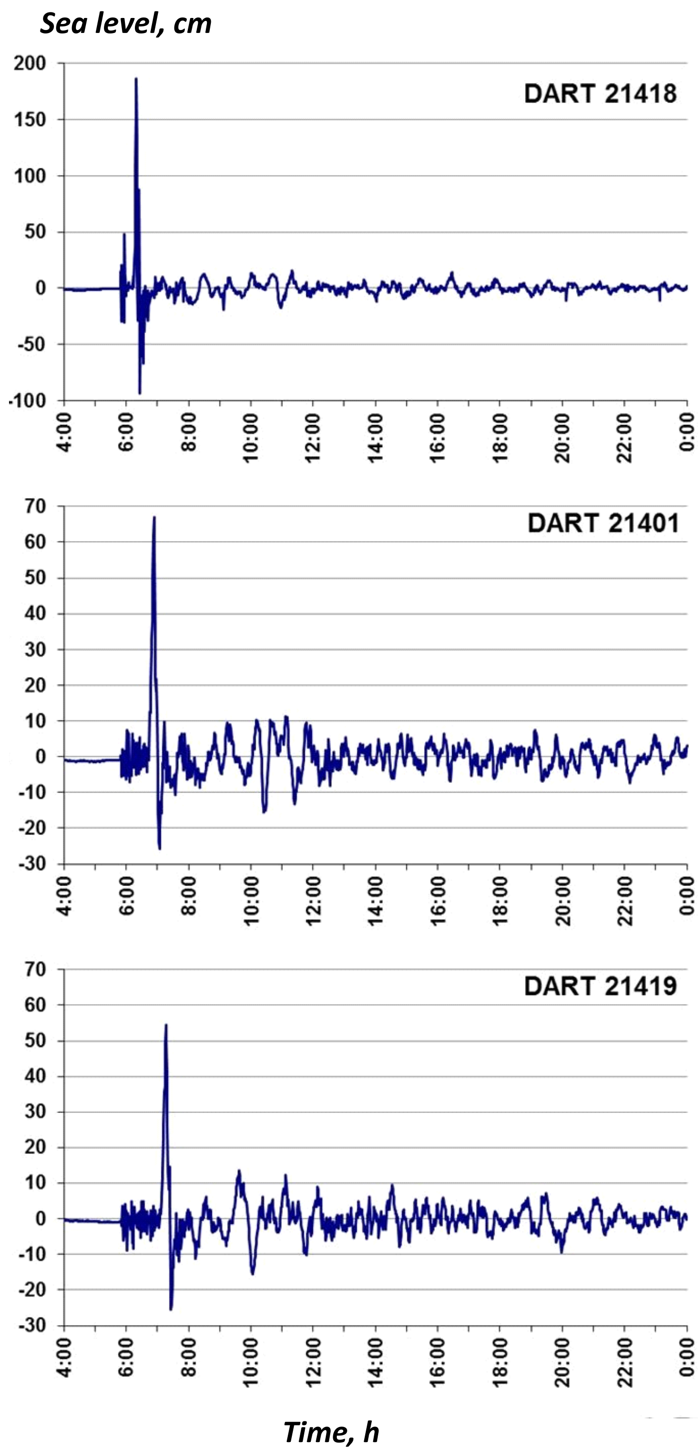

Fig. 2. 20-hour segments of the Tohoku tsunami of March 11, 2011 records, measured by the DART deep-water stations in the Northwest Pacific.

Also noted should be the expressed wave dispersion – specifically the high-frequency vibrations delay in comparison to the longer period components. Such effects are hardly identifiable at near-coastal stations because of the strong influence of reflected and refracted waves in the variable depth zone and the interaction with the coastal boundary. In the open ocean these fine effects are manifested very well in some cases.

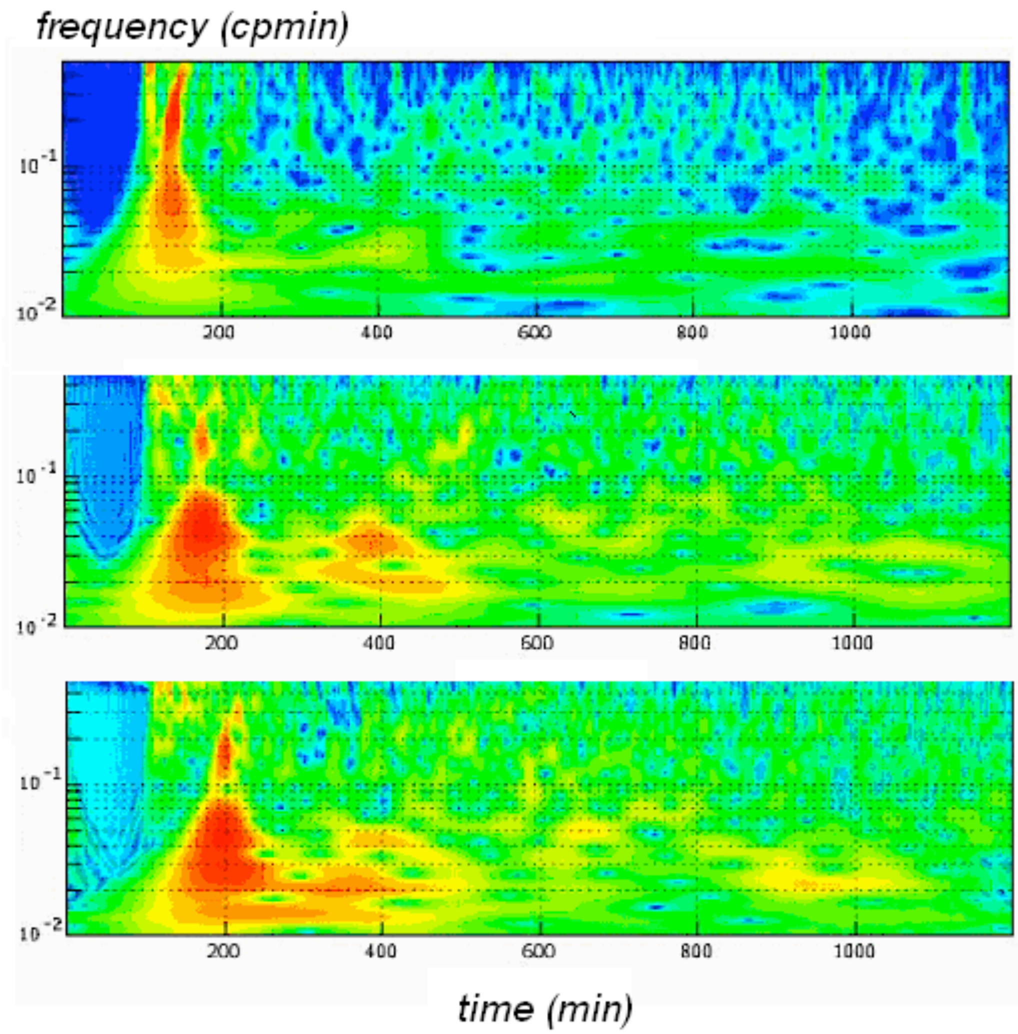

Fig. 3. Spectral-time diagrams of sea level oscillations at DART deep-water stations 21418, 21401 and 21419. The spectra are normalized to the amplitude value of 30 cm for station 21418 and to 10 cm for stations 21401 and 21419. Isolines are drawn with 1 dB step.

The calculated STA-plots were based on observations at DART stations, 214001 and 21419 which are nearly identical and generally have more predominant low-frequency vibrations in comparison to DART station 21418. For example, the main peak was associated with periods of 20~30 min and considerable energy was recorded in the low-frequency part of the spectrum (where the periods ranged from 50~80 min).

Such substantial difference in the energy distribution pattern is typical for a tsunami and is caused by the spatial extent of the source. Longer waves propagate in the direction of the long axis of the source region, while shorter waves, propagate along the shorter axis. The examples presented in this study validate clearly this relationship.

4. MEASUREMENTS OF TSUNAMI BY SHORE-BASED RECORDERS

Tsunamis that propagated towards the South Kuril Islands were first recorded at the Kushiro and Hanasaki stations along Northeast Hokkaido Island, first (Fig. 4a). Measurements of data presented in the Internet with sampling rate of 5 min, did not permit the determination of tsunami arrival time with the desired degree of precision.

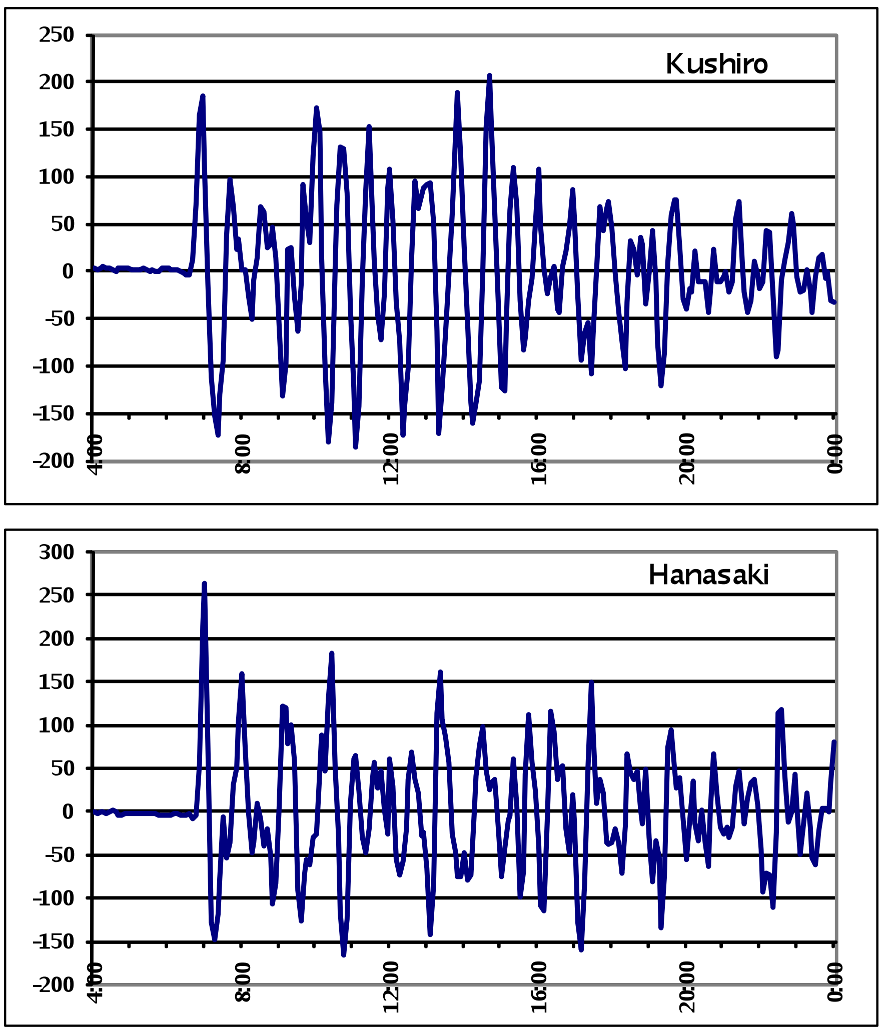

Fig. 4a. 20-hour segments of the Tohoku tsunami of March 11, 2011 records, measured by the coastal stations Kushiro and Hanasaki (northeastern Hokkaido Island).

The first tsunami wave front arrived at the Kushiro station at about 6:25 UTC. The first significant positive deviation from null average level (+185 cm) was recorded at 6:55 and the negative one (-173 cm) 25 min later. Intensive oscillations lasted for a quite long time and the maximum wave height (+207 cm) was recorded at 14:40. Afterwards, the intensity of oscillations decreased significantly, though waves of 50~70 cm in amplitude still were observed for a day.

At the Hanasaki station, the pattern of tsunami manifestation was different. Here, the first wave was clearly distinguished but then the amplitude of the oscillations gently decreased. The arrival time of the first wave front was approximately 5 min later than that at the Kushiro station, the same time interval that was between the first peaks, mainly in Hanasaki (+264 cm). The decreased level of the first wave was also significant (-147 cm at 7:15) and the wave height from trough to crest exceeded 4 m. The amplitudes of subsequent waves were substantially lower, though intensive variations at the Hanasaki station lasted generally for a period longer than those at the Kushiro station, approximately up to 19:30. The last wave of less than 1 m in amplitude was recorded near the end of the day, at 23:30, while on March 12, relatively weak waves of less than 40~50 cm in amplitude were still observed.

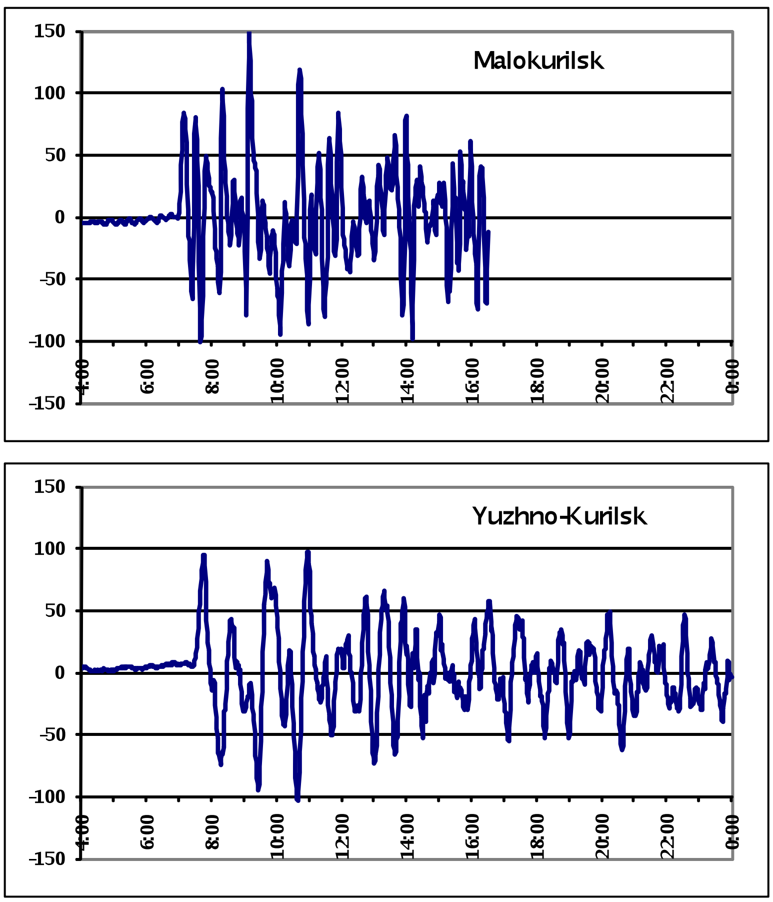

Fig. 4b. 20-hour segments of the Tohoku tsunami of March 11, 2011 records, recorded by the coastal stations of Malokurilsk (Shikotan Island) and of Yuzhno-Kurilsk (Kunashir Island).

Presently, there are three shore-based telemetric TWS sensors on the South Kurils, in Malokurilsk, Yuzhno-Kurilsk, and Kurilsk. The station in Malokurilsk did not operate at the time due to technical problems. The record of shore-based, self-recording, sea level gauge stopped at 16:30 UTC when it run out of ink. However, the most representative part of tsunami-induced oscillations had been recorded. The tide gauge pen-and-paper records were digitized with a 1 min time step and the resulting data used for a statistical and spectral analysis. Fig. 4b represents the plots of 20-h portions of residual (with tide filtered out) of sea level oscillations of the above-mentioned stations.

The record show that the tsunami arrived at Malokurilskaya Bay at 6:50 UTC only 7 min after its arrival time at DART station 21401. This indicates that if a tsunami were generated on the continental slope near the Pacific coast of Japan, then the deep-water sensor would not give any significant time advantage for the initiation of a tsunami warning. The more significant time advantage would be in case of earthquakes in the areas of Kuril Islands, Kamchatka Peninsula or for an event generated at a more distant high-seismic zone of the Pacific. Under the conditions of the March 11, 2011 tsunami, DART station 21401 played the most important role in the TWS operation, since the telemetric sensor in Malokurilskaya Bay was not operating.

The first tsunami wave in this open sea region was quite significant. The positive deviation was +84 cm (at 7:09) and the negative one -67 cm (at 7:24). The highest wave was recorded two hours later at 9:09 (150 cm) and the most significant decrease in sea level (-79 cm) was detected several minutes earlier at 9:04. Thus, the amplitude range between the wave crest and trough was 229 cm. It is interesting to note that the pattern of the March 11, 2011 tsunami manifestation in Malokurilskaya Bay substantially differed from that typical of the open sea area - the latter indicating a predominance of resonant oscillations with periods of about 19 min and an expressly grouped structure. The record in Kurilsk (Fig. 6) is closer to the described type. Observed in this case, are slightly irregular busts in intensity of variations throughout the entire analyzed portion of the record, though the period of the fundamental mode was the main one. Also identified were non-typical, low frequency oscillations in sea level of about two hours in period.

At Yuzhno-Kurilsk, in-spite of the relatively distant location of the water area discussed above, the pattern of the tsunami wave process was visibly different, due to the predominance of low-frequency oscillations. The wave front reached this station at 7:26, the first significant peak (95 cm) was recorded at 7:45 and the subsequent minimum (-74 cm) was at 8:17. The highest amplitude of the oscillations was observed much later, when the lowest trough (-103 cm) occurred at 10:39 and the peak crest (+98 cm) at 10:57, respectively. In general, the drop in energy was slow and oscillations of about 50 cm in amplitude lasted until the end of the day.

Fig. 5 represents the spectral-time diagrams of oscillations, calculated on the basis of 20-h portions of records at the Hanasaki and Yuzhno-Kurilsk stations. Since the sampling interval of the Hanasaki recorder was 5 min, the minimal possible period of spectral characteristics calculation is 10 min. Therefore, the calculation was carried out for the periods of 10-100 min for all stations. However, this restriction does not appear to be very important, since the high-frequency oscillations did not play a significant role in the tsunami waves observed on the South Kuril Islands.

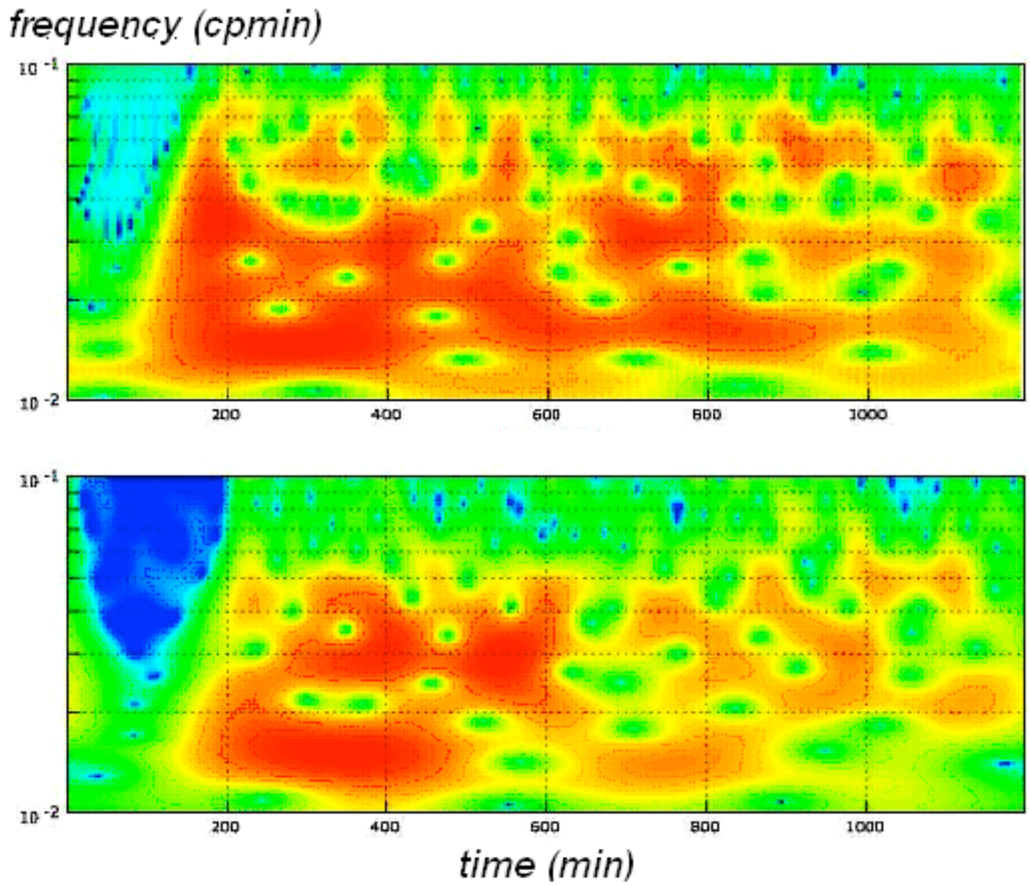

Fig. 5. Spectral-time diagrams for sea level variations at the Hanasaki and Yuzhno-Kurilsk. The spectra are normalized to the amplitude value of 60 cm for the Hanasaki station and to 30 cm for the stations at Yuzhno-Kurilsk. Isolines are drawn with a step of 1 dB.

At the Hanasaki station, the initial segment of the record is characterized by energy increase in a broad range of periods ranging from 20 to 80 min. We can identify the Particular peaks were identified at periods ranging from 25-30 min, 45-50 min and 70-80 min. Low-frequency vibrations had both significant spectral amplitudes (50-60 come) and a long duration, but this peculiarity is notable for the other mentioned peaks, as well.

At the Yuzhno-Kurilsk station, STA-diagram had nearly the same pattern, but with more clearly distinguished two peaks at periods of about 30 and 80 min. Intensification of low-frequency vibrations, manifested at two stations, is typical for the given region and is caused by the absence of shelf resonance. Such intensification is rarely observed, because the excitation of the corresponding component in the initial signal requires a powerful earthquake with large linear size of focal energy propagation. Previously, such case was created when the tsunami of May 24, 1960 caused by the great Chilean earthquake – known at the strongest in the 20th century in the Pacific (Ivel'skaya and Shevchenko, 2006). As has been shown above, the record from DART station 21401 contained the corresponding component. This indicates that the focus of the March 11, 2011 earthquake near northeast Honshu Island was also of a quite large extent.

The previously mentioned peak in the spectrum at a period of about 30 min might cause significant intensification of the tsunami in Krabovaya Bay (see the effects description below), because the period of its main resonant mode was 29 min (Rabinovich, 1993).

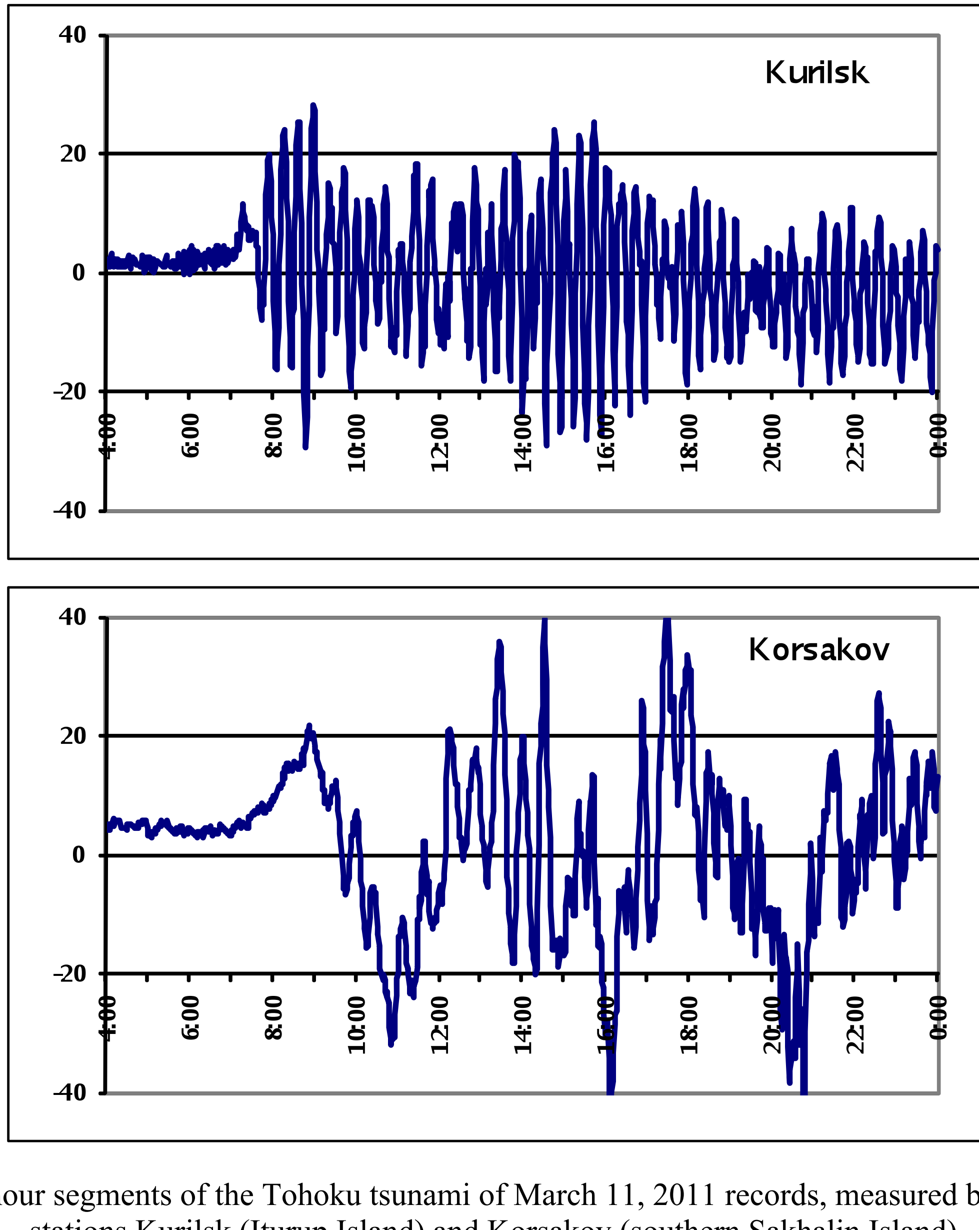

Fig. 6. 20-hour segments of the Tohoku tsunami of March 11, 2011 records, measured by the coastal stations Kurilsk (Iturup Island) and Korsakov (southern Sakhalin Island).

In Kurilsk (Fig. 6), the pattern of the wave process was unordinary for the given area: resonant vibrations of about 20 min in period dominated absolutely and the group wave structure was clearly expressed (wave trains contained 8-10 waves each). Such a pattern of tsunami manifestation is usually observed in bays with narrow entrance, like that at Malokurilskaya(Rabinovich, 1993). However, Kitovyi Bay, where the measuring instruments were placed, is referred to as a semi-closed bay with a long open boundary.

The moment of tsunami wave arrival at this station appeared to be hardly determinable, since it was unclear whether a small positive burst (+11 cm at 7:17) was part of the tsunami. The doubt is caused by the very early appearance of this peak. The highest wave was the fourth in the first wave train (-29 cm at 8:48 and +28 cm at 8:59) and oscillations of nearly the same amplitude were observed in the second wave train in the time period lasting from 14:30 to 16:00.

It is interesting to compare the above-discussed data from shore-based recorders with those from the deep-water station located in the open ocean near Iturup Island. Only the pattern at the Hanasaki station demonstrates certain resemblance with signal, non-distorted by shelf-related and coastal effects (this mainly related to the shape of the first wave). At all the other stations, the influence of local relief is so significant that it is impossible to identify any resemblance. This emphasizes the most important role played by the bottom relief peculiarities at the zone of sharp depth changes in the pattern of tsunami propagation; however, this is a factor that is often underestimated.

In Severo-Kurilsk, the telemetric sensor was switched off a day before the tsunami for the preventive maintenance and then switched on again in the morning of March 12. In-spite of the interruption, a wave of more than 80 cm in height was detected. In Petropavlovsk-Kamchatsky, due to the narrow strait, tsunami waves in the Avachinkaya Bay are usually substantially lower than in the open parts of the coast. This phenomenon was observed on March 11. The amplitude of sea level oscillations did not exceed 15 cm. In contrast to this, at the Semyachiki station in Kronotsky Bay, the maximum wave height was significant (82 cm at 15:28). At 8:37 the wave reached Nikolskoe port (Bering Island) and at 9:03 its height became maximum (25 cm). Subsequently, oscillations in wave height were quite long but with a small amplitude (15-20 cm).

Clear records of the tsunami were acquired on the south and southeast coasts of Sakhalin Island. In Korsakov port, the tsunami wave arrived at about 7:40 (Fig. 6). Here, very low-frequency sea level oscillations with period about 4.7 hours were observed, which are related to the zero resonant mode of Aniva Bay and are usually predominant when tsunami strikes. This peculiarity manifested on March 11, 2011, as well. The maximal wave in amplitude was detected much later than the tsunami arrival (-42 cm at 16:09 and +47 cm at 17:30). At the Kril'on Cape station, which is located in the vicinity of a nodal line of the bay's main mode, oscillations were substantially more high frequency and relatively weak (the amplitude did not exceed 15 cm).

In the record from the Starodubskoe station, a clear moment of wave arrival cannot be identified - however, it was most likely at 8:05. The first well-expressed peak occurred at 8:44 (24 cm). The maximum wave height (+33 cm) was observed much later, at 15:10, while the maximum amplitude between the crest (+30 cm at 22:34) and trough (-31 cm at 21:51) was detected more than 7 hours later.

In Poronaisk, the tsunami-caused oscillations were of similar pattern, but manifested much later. The arrival time of the wave front was detected at 10:06 and the first well-expressed peak (+38 cm) was observed at 10:38, nearly 2 hours later than at the Starodubskoe station. Such a big time shift between the relatively close points is caused by significant propagation time of long waves within the shallow-water Terpeniya Bay, in whose farthest corner the Poronaisk station is located.

The maximum amplitude of oscillations was identified here more than 7 hours after the first wave arrival: at 17:11 for the minimum (-33 cm) and at 17:53 for the maximum (+44 cm). Intensive oscillations at this point lasted for about a day. For example, the wave of nearly same amplitude was detected about a half-day after the first maximum (+35 cm at 8:51 and -37 cm at 9:26 on March 12).

Let us consider the peculiarities of Tohoku tsunami penetration into the Sea of Japan. The Tsugaru Strait that divides Hokkaido and Honshu islands is located close to the source and, despite its narrow width and complex pattern of coastline, possesses a good conducting ability because of its sufficient depth. The first wave arrived at the Hakodate port in this strait approximately an hour after the earthquake, at about 6:45. The maximum of the first wave (+163 cm relative to the average level) was detected at 7:35 and 20 min after this the sharp decrease in level (-131 cm) occurred. The maximum amplitude of oscillations was observed two hours later (+203 cm at 9:55, -155 cm at 10:15). Another high wave (+226 cm) was detected much later, at 16:35.

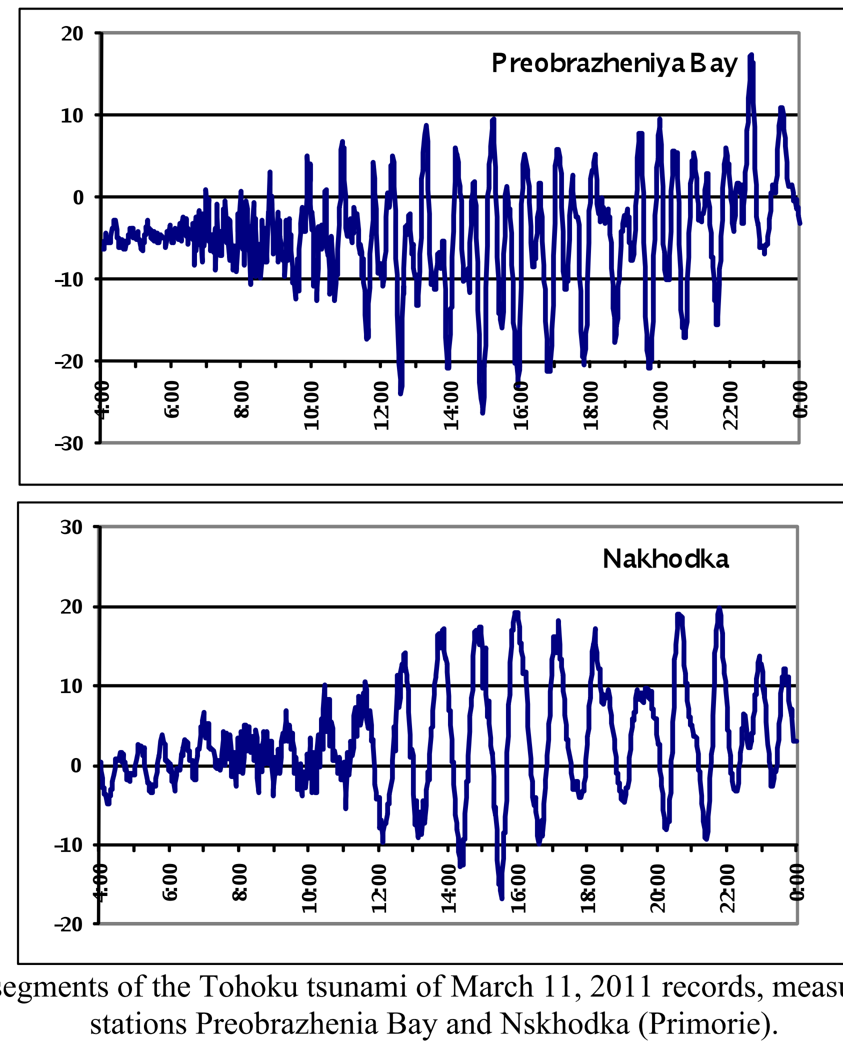

Fig. 7. 20-hour segments of the Tohoku tsunami of March 11, 2011 records, measured by the coastal stations Preobrazhenia Bay and Nskhodka (Primorie).

The tsunami was recorded by shore-based instruments in Primorye (Nakhodka, Preobrazheniya Bay, Rudnaya Pristan) and on west coast of Sakhalin Island (Nevelsk, Kholmsk, Uglegorsk). Determination of tsunami arrival time at these points was very difficult, since the intensity of tsunami-related oscillations was relatively small and the level of long-wave noise had increased (most likely due to weather deterioration) several hours prior to tsunami arrival. It is firmly believed that the first tsunami-related peak was +4 cm at 8:48 (see Fig. 7), which is slightly more than an hour later than the wave arrival at the Hakodate station. In Nakhodka Bay, the tsunami wave arrived at about 9:00 local time and the first maximum (+6 cm) was at 9:20. The maximum oscillations at this location were observed much later: in Preobrazheniya Bay, the minimum (-26 cm) was detected at 14:55 and the maximum (+10 cm), at 15:14. In Nakhodka Bay the minimum (-17 cm) and the maximum (+19 cm) were at 15:32 and 15:59, respectively. Generally, at the similar pattern of intensity oscillations with time for these two stations, a visible difference in predominant periods is notable: about 0.5 h in the Preobrazheniya Bay and about 1 h in the Nakhodka Bay. These differences are caused by resonant properties of these water areas, due to their spatial extent and depth. In Rudnaya Pristan, resonant oscillations of about 1 hour in period also dominated and their maximum amplitude was 15 cm.

Tsunami waves reached the southwest coast of Sakhalin Island much later than the Primorye coast. For example, the southernmost station in Nevelsk detected the first positive deviation (+9 cm) at 10:58 and stable oscillations dominated in the record. This is quite extraordinary phenomenon, since these is no bay in this area (since it is in bays, where stable oscillations of resonant type can manifest). The highest wave amplitude was 27 cm (+15 cm at 14:56 and -12 cm at 15:10).

The most distant station in Uglegorsk recorded tsunami wave arrival at about local midday, but the intensity of waves increased much later. For example, the highest amplitude was the minimum -3 cm at 22:04 and the maximum +15 cm 22:19. In the records, the stable oscillations of about 50 min in period were identified - which may be most likely related to the transversal seiche of the Tatar Strait.

5. CONCLUSIONS

The present study analyzed a great volume of instrumental measurements data of the Tohoku tsunami on March 11, 2011, as acquired at the deep-water and shore-based sensors in the Russian Far East. The great difference between the signal in the open ocean and in the coastal zone has been visually illustrated. In the former case, powerful singular pulses and subsequent relatively weak oscillations were observed, while the long-term intensive oscillations were recorded in the latter case (only at the Hanasaki station the first wave was of maximal height). The pattern of variations near the shore was determined mainly by local topography; the general properties caused by the processes of the tsunami source manifested less intensively.

Resulting from the analysis of deep-water stations data, was determined that shorter waves (with main peaks of 6-8 and 15-20 min) propagated eastwards, to the open ocean side, while longer waves (with main peaks of 25-30 min) radiated to the side of Kuril Islands; the significant energy was identified in the low-frequency part of spectrum at periods ranging from 50-80 min. The low-frequency component significantly intensified on the extended shelf of the South Kuril Islands and played an important role in the formation of tsunami-caused oscillations at the Hanasaki, Malokurilskoe and Yuzhno-Kurilsk stations. In far field, the local topography effect manifested differently: the most important role in tsunami-caused oscillations was due to bays' resonant modes.

In the most investigated points (in densely populated settlements of Yuzhno-Kurilsk, Malokurilsk and Severo-Kurilsk) the tsunami heights ranged from 2-2.5 meters. The highest waves were detected in Krabovaya Bay, Shikotan Island (about 3 m). Most likely, this was caused by the presence of the peak at the period of about 30 min in the initial signal. Such period is close to the period of the bay's main mode and this proximity led to resonant strengthening of the sea level oscillations.

The Tsunami Warning issued from the Sakhalin TWS for the localities on Kuril Islands was reasonable, because such wave heights were of a serious danger for vessels in the ports, as well as for workers at industries and local inhabitants in the coastal zone.

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